DOCUMENT RESUME

ED 226 695 IR 009 529

AUTHOR Waller, Robert
TITLE Understanding Network Diagrams.
PUB DATE Apr 81
NOTE 17p.; Paper presented at the Annual meeting of the American Educational Research Association (Los Angeles, CA, April 1981).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Design Requirements; *Diagrams; *Flow Charts; Higher Education; *Instructional Materials; Networks; Textbooks; Visual Learning; *Visual Stimuli
IDENTIFIERS *Visual Representation

ABSTRACT

A survey of a range of introductory university level textbooks in the social sciences found little use of network diagrams (NDs), i.e., graphic representations of processes, organizations, systems, and mechanisms. NDs can be viewed as a text/picture hybrid medium with titles and captions serving to qualify and identify the meaning and status of symbolic forms plus a spatial dimension not present in linear prose; most fall somewhere in the middle between strict notational systems and visual metaphors or symbolic diagram construction or the problems involved in their comprehension. The cognitive and linguistic problems of diagram construction and interpretation are the subject of a number of exploratory studies designed to identify the major factors for future, more detailed studies. One such preliminary study involved the production and identification of diagrams by nine Open University employeees to communicate specific sentences. Results indicated, that there was little significant consistency in the subjects' choice of graphic devices in the production experiment. In a related identification experiment, however, sentences were signficantly easier to identify. This report includes 16 references and an appendix containing the repertoire of graphics and sentences to be displayed together with the diagrams produced by four subjects. (LMM)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

U S DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

ED226695

UNDERSTANDING NETWORK DIAGRAMS

Robert Waller
Institute of Educational Technology
The Open University

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

R.H.W. Waller

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Paper presented at the annual meeting of the American Educational Research Association, Los Angeles, April 1981

Acknowledgement: The work discussed in this paper forms part of a wider project in collaboration with Michael Jones and Jane Wolfson of the Open University Continuing Education Division.

RC019529

Network diagrams (NDs) are graphic representations of systems, processes, organisations and mechanisms. They are distinct from pictures, which depict or describe the surface appearance of objects and scenes, and from quantitative charts and tables that display statistical data for ease of access and comparison (although NDs are sometimes combined with one or both of these). Typical topics of NDs include the electoral system, a company structure, a family or social structure, an industrial process or a biological process. Figure 1 lists typical semantic structures found in NDs, either singly or in combination.

NDs offer an intriguing but apparently almost untouched area of research. Literature search is confounded by the variety of terms used (verbal chain diagram - Gropper, 1970; block word diagram - Holliday, 1976; logical diagram - Knowlton, 1966) but it seems that although NDs and similar devices are often mentioned in the course of a discussion of some other instructional medium or variable, little analysis or experimentation has concentrated on them. This is strange, since there has been a proliferation in recent years of research or pictorial imagery, and also on various prose overview or pre-instructional devices. NDs, too, are frequently used to augment a complex prose explanation or to overview the structure of a book or chapter and so intuitively might be thought to share some of the functions ascribed to both pictorial and textual adjunct devices.

It is hard to assess how common NDs are. We surveyed a range of introductory university level textbooks in the social sciences and were surprised at how few we found. Even disciplines to which the study of organisations and systems is central (such as economics, sociology, anthropology, management studies) used very few diagrams. Several explanations are

possible. It could be that prose is consistently adequate without the aid of adjunct diagrams; it could be that most authors have high verbal skills and low visual skills, and simply find it hard to visualise their ideas; or it could be that diagrams are too expensive for publishers to contemplate.

It is true that diagrams can be expensive to prepare and to print; this is partly because of the second factor above - authors who are poor visualisers need the services of a graphic artist. This collaboration is time consuming, inconvenient and expensive, and it seems that even those publishers who do tolerate a high illustration content prefer to lard the author's prose with stock picture-library photographs which require little consultation and no special preparation.

If NDs are so rare, is it worth investigating them? It can be argued that if more was known about them, they would be less rare. If visual literacy - the ability to understand and create pictorial and diagrammatic communications - were more widespread, authors (who may already use diagrams in their personal notes and in lectures) might be better equipped to use diagrams with less need for professional mediation. Our assessment of the 'state-of-the-art' of diagram design is that the professionals, too, could benefit from a more systematic approach to the issue. Too often the structure of NDs is obscured by the sort of decorative effects that Tufte (1978) has dubbed 'chartjunk', and too often an inadequate first draft is accepted uncritically and tidied up for publication when a radically restructuring is necessary. Because few agreed rules exist for either their construction or their interpretation, it is common to encounter diagrams at one extreme which display hopelessly confused tangles of lines and boxes (no structure at all), or, another extreme, take an outward shape which is attractive or symmetrical, or one borrowed from another diagram altogether (an inappropriate structure). Somewhere between unstructured chaos and an artificial externally-derived structure lies a notional 'correct' structure (or choice of structures) that

is appropriate to both its message content and the needs of its user.

Diagrams versus prose?

But how is this 'correct structure' determined. In the case of prose communication there are agreed standards of grammaticality, and lists of acceptable words (dictionaries and common-word lists); and it is possible to recommend stylistic and rhetorical strategies from a long tradition of literary scholarship, and a more recent tradition of psycholinguistic research. Scarcely any of these exist for NDs, and consequently research should proceed cautiously - extrapolations from individual studies to general rules and guidelines may not yet be possible. For instance, Barnard and Marcel (1978) and Szlichcinski (1978), in similar studies of the use of pictorial instructions for equipment operation, reported opposite results. Szlichcinski (1979) has concluded that "the optimum amount of detail in diagrams [the variable explored] is very sensitive to task and population differences."

If diagrams are indeed sensitive to such relatively subtle population differences, then the conclusion seems to challenge the assumption of many that graphic communication is more universal in application than verbal language. Barnard and Marcel (1978) directly compared verbal and graphic languages; they point out that whereas prose works within a widely shared syntactic and semantic framework, graphic communication can only draw on a strictly limited repertoire of isolated rules and conventions. The integration of information supplied by the graphic medium is left largely to the reader, who must make inferences from his knowledge of the visual world and from his deduction of the internal logic of the image (which may not correspond with graphic systems used in other images).

Parsing diagrams

Having said that, there are nevertheless NDs which appear to be relatively amenable to parsing. It is possible to detect noun-equivalents (boxes), verb-equivalents (arrows, lines), adjective and adverb equivalents (captions, graphic codes such as tints, relative sizes, and colours. Figure 2 lists the components of a typical ND.

However, the analogy with verbal language only works up to a point - it breaks down when we compare the scale of vocabulary in each medium. Many thousands of words can be discriminated, but there are strict limits to our ability to handle systems of visual stimuli such as are used in NDs. In addition, it is only possible to parse language forms which consist of discrete units. Many diagrams, though, like pictures, present an essentially unified image that demands an entirely different form of analysis. Progress in this area may be anticipated not, as one might expect, from historians and philosophers of art, but from artificial intelligence and robotics research, where there is a need to provide machines with a means of making rudimentary digital 'sense' of the analogue visual environment.

It seems more realistic to view NDs as a text/picture hybrid medium rather than as the alternative to prose that idealists would sometimes like (Biderman, 1980). That is, titles and captions are vital qualifiers and identifiers of the meaning and status of the symbolic forms used in NDs while NDs add a spatial dimension not present in linear prose. Thus Figure 2 follows Garland (1979) in including 'title' and 'caption' as integral components of a diagram.

It is this spatial and graphic dimension that seems to be so hard to pin down with a syntactic system. It is possible to classify simple stylistic features, as Bertin (1967) has done,

and to identify a number of configurational strategies - clustering, aligning, linking, overlapping, branching, for example - but there appears to be no visual equivalent of 'correct' verbal syntax that enables us to distinguish acceptable from unacceptable forms, without reference to context or meaning.

Visual argument

If there is no shared content-free syntax for NDs, what is it that enables them to be understood (or not, as the case may be)? What resources do their originators draw upon in their construction? And how do readers process them?

It is possible to identify two ends of a continuum of sources of visual argument. 'Visual argument', a term first used by a pioneer of graphic communication techniques, Otto Neurath (Kinross, 1981) refers to the rationale for the selection and configuration of diagram components.

At one extreme there are notational systems, which do have a syntax of the sort we were seeking. Nelson Goodman's (1976) theory of notation lays down strict criteria for determining the notationality of a symbol system. Expressed simply, a 'pure' notation (and he admits very few) is a rule-bound system of semantically and syntactically discrete and disjoint characters - there can thus be no doubt about the meaning (which is thus context-free) of a particular character or sequence of characters. Some pure notations may not be truly diagrammatic, but many diagrams display some notational characteristics - among their users there is high agreement about their construction and interpretation, and their use of imagery tends to be highly abstract. Computer

programming flowcharts are an example of notational diagram—system - they have well-agreed patterns of use, but are not sufficiently comprehensive in scope to be uncontroversial (Fitter and Green 1979, Richards and Johnson 1980).

At the other extreme are visual metaphors, or symbolic pictures. Like prose metaphor, this involves reference to shared experiences of the natural world to explain how systems work by analogy. Political cartoons and allegorical paintings could be thought of as visual metaphors, although, again, in a comprehensive classification system of visual imagery they would have to be regarded as distinct from diagrams. It is interesting to note that the allegorical images that often appeared on the frontispiece of many early scientific books are direct precursors of the NDs that take their place today.

High metaphor diagrams can be opposed to high-notation diagrams not only because their characteristic imagery is different but because they rely almost entirely on the contextual and cultural background knowledge of the reader. What Gombrich (1960) called 'the beholders share' thus plays a greater role in the interpretative process. Consequently while notational scripts from ancient civilisations can be read once the code is cracked, the meaning of symbolic or allegoric pictures is often lost to future generations who do not share the contextual knowledge of its original audience. And diagrams in textbooks which borrow imagery from ephemeral contemporary culture will also be susceptible to similar incomprehension. International publications are particularly vulnerable to this.

Somewhere between notation and metaphor lies a set of conventional patterns. By pattern is meant a format or structure which is well understood within a cultural group

but which is neither as strictly rule-bound as notation nor as open-ended as metaphor. An example of a pattern is a tree diagram. Originally used as a metaphor for a set of diverging elements stemming from a single source, these were once printed as literal trees - with twigs and leaves. Now they have become abstract patterns, but are read correctly because they are implicitly accepted as tree structures (diverging from a source) as distinct from, for instance, rivers (which converge from multiple sources). Patterns can be thought of as dead or embedded metaphors, although some have notational origins. For example Venn diagrams, chemical models and electrical circuits have all been absorbed into our visual culture.

Problems with diagrams

Our survey of diagrams indicated that the majority of NDs fall somewhere in this middle area - many use combinations of different patterns, notational rules and metaphors to a degree that seems to defy simple analysis. It is perhaps surprising, in view of the inability of students of verbal language to agree on how it is generated and understood, that the classification of visual imagery has tempted so many, when its complexity is compounded by extra, interfering effects; for example, most linguists feel able to assume that texts they analyse are 'mature' examples; children's language is studied in a different, developmental, context. But we were forced to conclude that many of the examples we examined were, in effect, immature or unskilled products. In addition, there are effects or problems arising from the economics and technology of the printing process - unlike verbal language (as normally conceived) NDs are in their most usual form mediated by industrial processes.

Figure 3 lists some of the problems which we found with NDs that we surveyed. We have distinguished between three classes of problem - perceptual, cognitive or linguistic, and rhetorical.

In planning a programme of research into some of the issues that emerged from the survey, we considered the perceptual area relatively well covered in the general psychological literature. Rhetorical problems we chose to tackle in a critical, analytic way, using commentators from a range of relevant disciplines - linguistics, psychology, sociology, educational technology, graphic design - to analyse the role of particular diagrams in the context of a total argument (Waller and Anderson, 1981). Cognitive and linguistic problems of diagram construction and interpretation are the subject of a number of exploratory studies, designed to identify the major factors for more detailed studies at a later date. One such exploratory study will be described.

The flowchart study

A problem with NDs of the more abstract, notational kind is that a limited repertoire of graphic devices is available to express a wide range of semantic structures (such as those listed in Figure 1). In addition to this referential function, similar devices are also used to express study/inspection advice (Start here, see over page, etc) and to link captions with particular diagram components.

Production experiment As a preliminary to a larger study to take place later in 1981, nine subjects (Open University employees, with no graphic design training) were given a repertoire of 10 styles of boxes or end-points, and 14 styles of arrow or line. They were asked to select the appropriate devices to construct a ND to display eight sentences, which we provided (Appendix 1). They were also asked to rate their confidence about their judgement on a four point scale, and were invited to suggest new devices if they found the choice inadequate.

Identification experiment In a second stage, subjects were presented with the drawn-up diagrams of four other subjects who had previously completed the task. Each set was in random order, and subjects were asked to match sentences to diagrams (Appendix 2).

The sentences chosen expressed a range of dynamic relationships between two unspecified objects or people, A and B. In addition, one categorial distinction and one caption/diagram link were listed.

Outcome With the exception of sentence 7 (continuous flow) there was little significant consistency in the choice of graphic devices. Many subjects found the task difficult, and complained that not enough devices were provided. In spite of this, there was hardly any response to the invitation to suggest devices not provided.

An interesting result did emerge, however, from the identification experiment. Table 1 shows the number of times each sentence was correctly identified. Sentences 1, 2 and 7 were significantly easier to identify and sentence 5 scored poorly. This success rate appears to correlate well with the confidence judgements from the production experiment (Table 2). So subjects were as confident about their own ability to express sentences 1,2 and 7 in diagram form.

Interestingly, subjects' identification of other subjects' choices was not affected by the decisions they had made themselves in the production experiment; nor did they appear to identify the same diagram in the same way each time it appeared, but seemed to be able to accept a different graphic rationale from each of the four original 'designers'. A very few subjects were completely in accord with the entire set of diagrams produced by on of the designers, but on the whole fewer than half were guessed correctly.

The study is being repeated with more control of subjects, who are being tested for visualiser/verbaliser bias, and using combinations of semantic structure in each diagram.

REFERENCES

Barnard P and Marcel T (1978)
Representation and understanding in the use of symbols and pictograms.
Paper presented to Nato conference on Visual Presentation of Information,
Het Vennenbos, The Netherlands,

Bertin J (1967)
Semiologie graphique: les diagrammes, les reseaux, les cartes.
Mouton, Paris.

Biderman AD (1980)
The graph as a victim of adverse discrimination and segregation
Information Design Journal, vol 1, no 4, 232-241

Fitter M and Green TRG (1979)
When do diagrams make good computer languages?
International Journal of Man-machine Studies, vol 11, 235-262

Garland K (1979)
Some general characteristics present in diagrams denoting activity,
event and relationship
Information Design Journal, vol 1, no 1, 15-22

Gombrich EH (1960)
Art and Illusion
Phaidon Press, Oxford

Goodman N (1976)
Languages of Art (second edition)
Hackett Publishing Company, Indianapolis

Gropper GL (1970)
The design of stimulus materials in response-oriented programs
AV Communication Review, 18, 129-159

Holliday WG (1976)
Teaching verbal chains using flow diagrams and text
AV Communication Review, vol 24, no 1

Kinross R (1981) in press
Graphic communication with Isotype
Information Design Journal, vol 2, no 2

Knowlton JQ (1966)
On the definition of 'picture'
AV Communication Review, vol 14, no 2, 157-184

Richards C and Johnson R (1980)
Graphic codes for flow charts
Information Design Journal, vol 1, no 4, 261-270

Szlichcinski KP (1978) Factors affecting the comprehension of pictorial
instructions.
Paper presented to Nato conference on Visual Presentation of Information,
Het Vennenbos, The Netherlands.

Szlichcinski KP (1979)
Diagrams and illustrations as aids to problem solving
Instructional Science, 8, 253-274

Tufte ER (1978)
Data graphics
Paper presented to the First General Conference on Social Graphics, Leesburg, Virginia.

Waller RHW and Anderson DC (eds) (1981)
Diagrams in argument: an interdisciplinary analysis
The Open University Institute of Educational Technology, Milton Keynes

Table 1. Number of correctly identified sentences

1	XXXXXXXXXXXXXX
2	XXXXXXXXXXXXXX
3	XXXXXXXX
4	XXXXXXXX
5	XXXX
6	XXXXXXXXXX
7	XXXXXXXXXXXXXXXXXXXX
8	XXXXXXXXX

Table 2. Confidence scores for production task

1	XXXXXXXXXXXXXXXXXXXX
2	XXXXXXXXXXXXXXXXXXX
3	XXXXXXXXXXXXX
4	XXXXXXXXXXXX
5	XXXXXXXXXXXX
6	XXXXXXXXXXXXXXX
7	XXXXXXXXXXXXXXXXXXX
8	XXXXXXXXXXXXX

categorial	
hierarchical	as in chains of command, taxonomies etc
overlapping	as in Venn diagrams, matrices etc.
comparative/ contrastive	as in a continuum, in parallel series/timelines, statistical charts, reflections, and various other symmetric or axial graphic devices.
discrete	as in simple lists (of words or pictures etc).
dynamic	
temporal	as in calendars, year-plans, time-lines
serial	as in various non-temporal (that is, where timing is not of the essence) series of events/processes; includes cyclical series.
causal	as in algorithms, certain operating instructions, feedback charts.
cumulative	as in recipes, production process/flow charts, where a given node accumulates new characteristics as a result of various inputs/interactions.
spatial	*both literal/geographic and abstract/ideational*
locational	town plans, 'physical' maps
territorial	organisational charts, 'political' maps
networks	route maps, circuit diagrams

Figure 2. Graphic components of typical network diagrams

elements	representing single concepts; the smallest particle in a particular diagram.
clusters	groups of connected elements that can themselves be treated as single elements (ie, linked as a whole to other elements or clusters).
connectives	representing links of various kinds between nodes/ensembles.
captions	which identify or qualify elements, clusters or connectives. Captions can be words, numbers, symbols, arrowheads, pictures etc.
boundaries	identifying the edge of a cluster, or defining the domain of a meta-level caption.

Figure 3. Common problems in diagramming

perceptual

figure-ground discrimination

colour vision

categorial discrimination (magic number 7 etc etc)

alignment/gestalt perception

cognitive/linguistic

no or vague 'grammar' of graphic marks

cross-cultural problems of interpreting metaphor or pattern

same devices used for different purposes (lines, arrows)

little correspondence in use of conventions between diagrams

interference from stylistic or decorative devices ('chartjunk')

rhetorical

less subtlety than prose; no qualifiers (sometimes, perhaps etc)

difficult to indicate/perceive personality of source (I, we, they, all scientists, some scientists etc)

fewer illocutionary cues (is it a proposal, a statement of fact, etc)

1

2

3

4

5

6

7

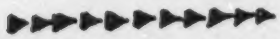
8 E

9 e

10

2

3

4 

5

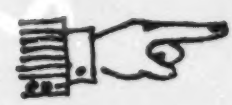
6

7

8

9

10

11 

12

13

14

1 A speaks to B

2 A controls B

3 A goes to point B

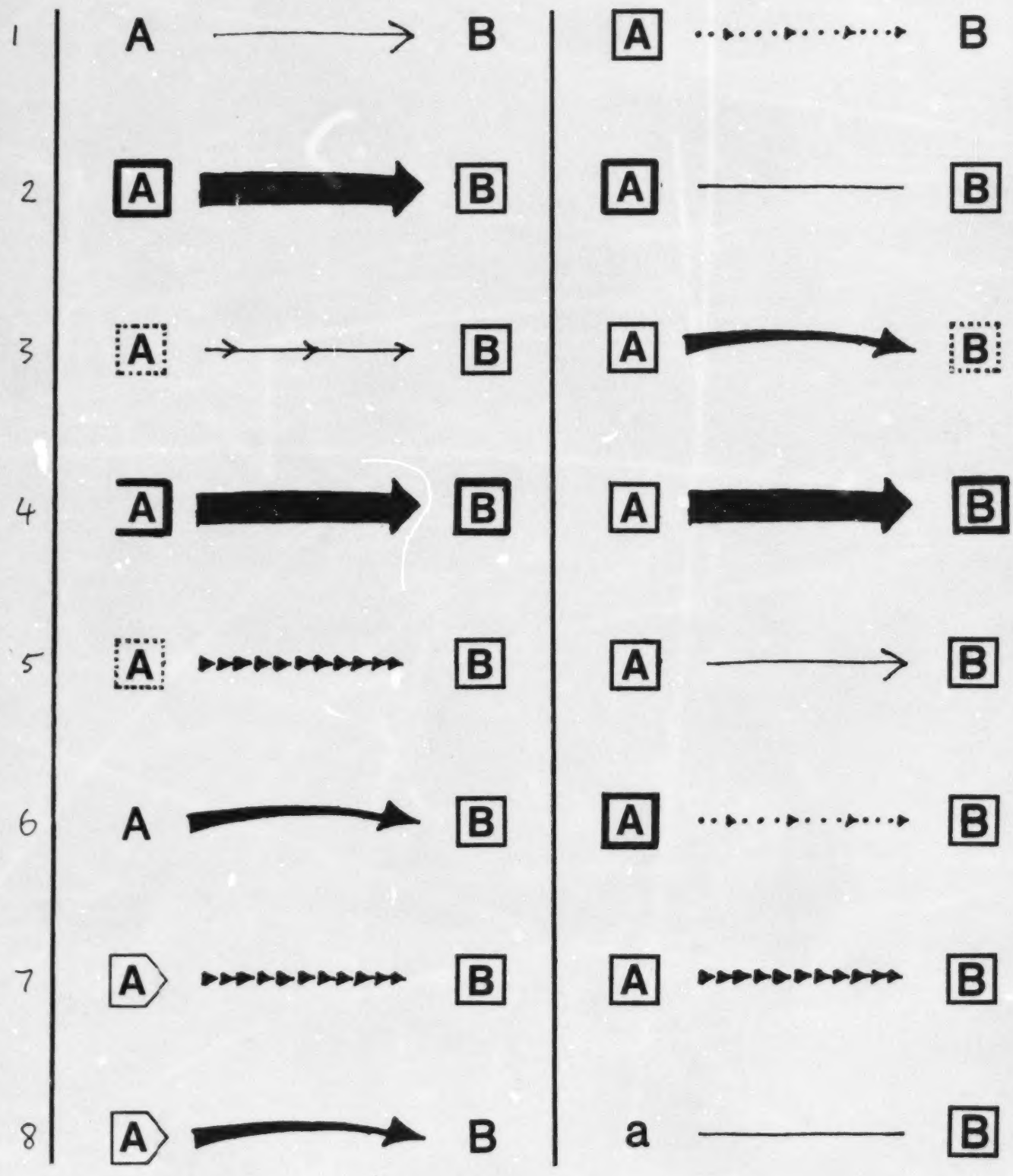
4 B takes something from A

5 A is changed into B

6 A gives something to B

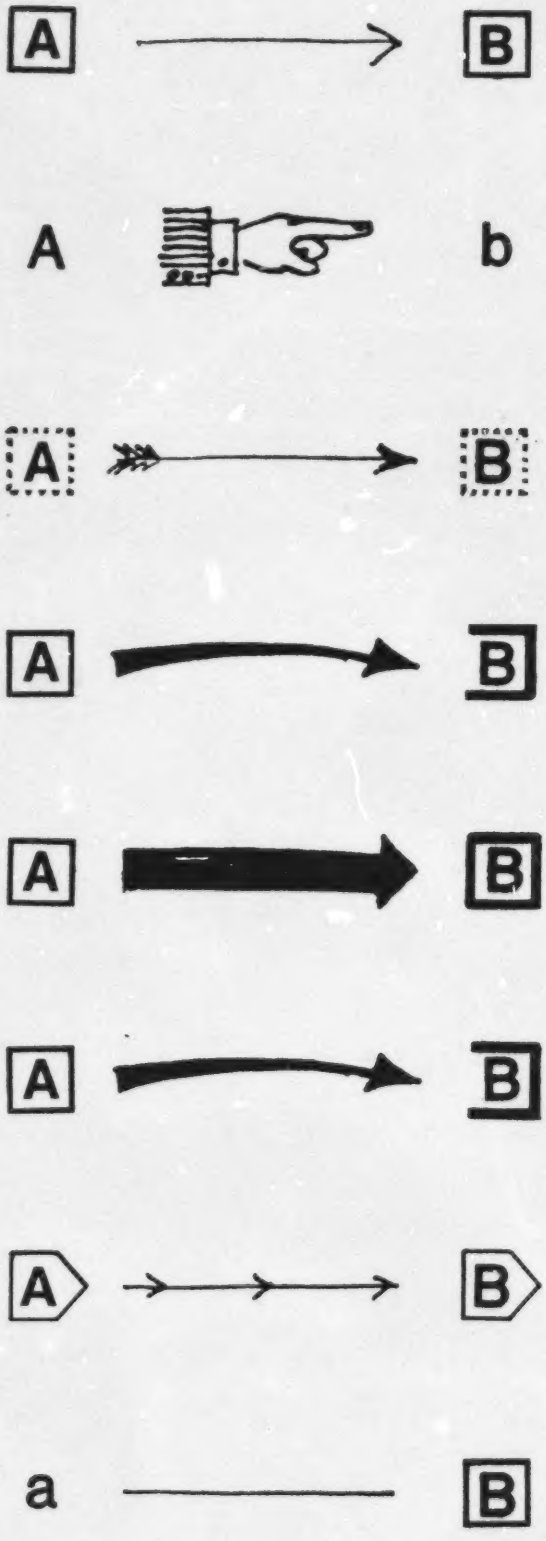
7 There is a continuous flow of movement from A to B

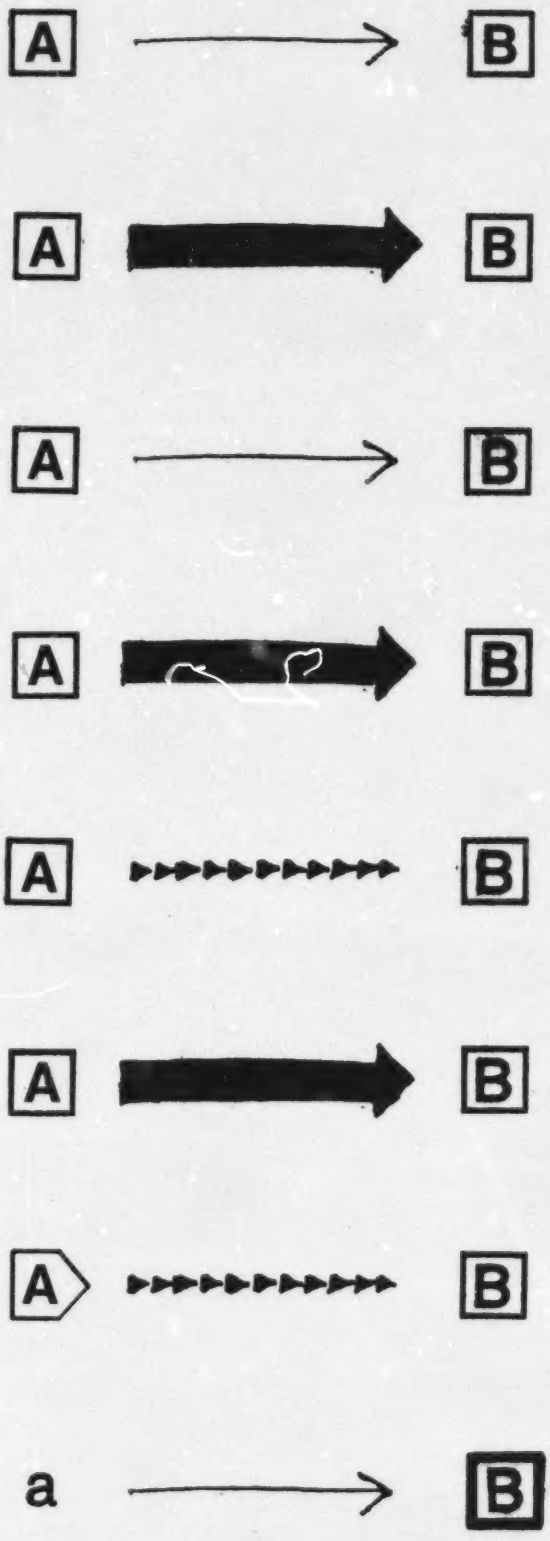
8 This caption (A) refers to B



subject a

subject b





subject c

subject d